# Processing Methods for Advanced Materials

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# Outline

- Advantages of advanced materials
- Composite material application
- Advanced material processing
  - Composites
- High Density Infrared (HDI) processing
  - Composites
  - Coatings
  - Intermetallic alloys
- Proposed activity

# Advantages of Advanced Materials

- Higher operating temperatures
  - Increased durability, more efficient furnaces, removal of ancillary cooling equipment
  - Ease the difficulty in applying high temperature direct and indirect convection systems
- Increased corrosions resistance
  - Extended service life
- Lighter weight
  - Ease in installation and maintenance
- Stronger and higher creep resistant
  - Extended service life
- Leads to higher efficiencies and lower maintenance lending to decreased costs
- Help accelerate the development of innovative process heating equipment
- Main challenge:
  - Advance the processing methods to develop reliable cost effective advanced materials

# Composite Materials Application

- One specific application of advanced composite materials
  - Recirculating fans for furnaces
  - Such applications as:
    - ➔Chemical plants – circulate corrosive gases
    - ➔Steel making process – circulate hot particle laden exhaust gases

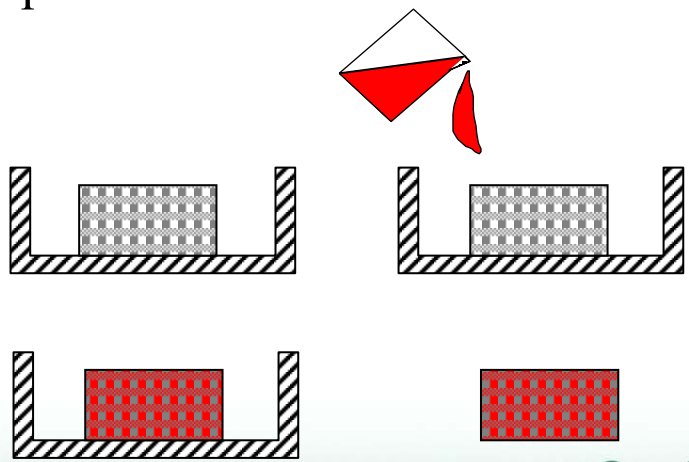
Advanced material fan blades can provide operational and energy efficiency advantages in heat treating process

# Advanced Materials Processing – Composites

- Two composite fabrication methods
  - Slurry Processing
    - ➔ Metal and ceramic slurries
  - Continuous Fiber Ceramic Composites (CFCC)
- Slurry processing
  - Process which utilizes a powdered material suspended in an aqueous or organic solvent and a porous support structure
  - Slurry is poured or pulled into the structure under vacuum
  - Densification can be traditional via sintering furnace or utilizing high density infrared processing (HDI)

# Slurry Processing - Continued

- Complex shapes are feasible
- Process is diverse (material chemistry is easily varied)
- Previous work at ORNL
  - Silicon slurry infiltration into a carbon fiber mat
    - ➔ Sintered at 1400°C for one hour
  - Formation of SiC with fiber morphology retained
    - ➔ Designed for microwave absorption – little characterization was performed
    - ➔ Density ~1.1 g/cm$^3$
    - ➔ Strength sufficient for furnace structural components up to ~ 1400°C in nitrogen



# Advanced Materials Processing – CFCCs

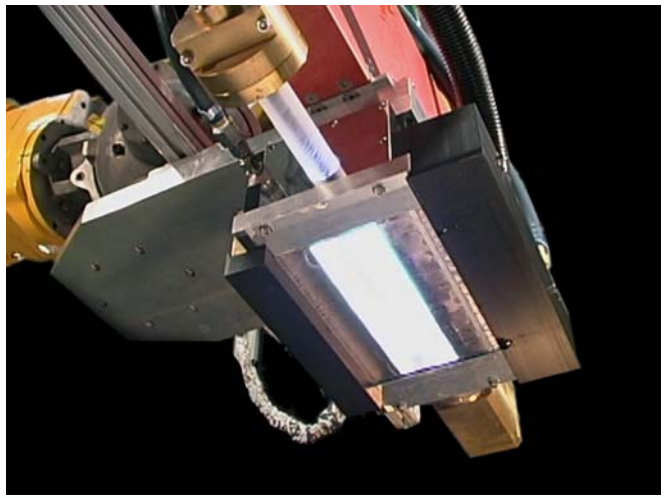
- Extensive mechanical characterization of SiC/SiC CFCCs have been performed at ORNL by MCAUC
  - Tensile strength
  - Creep resistance
  - Fatigue behavior
  - Environmental effects
  - Developed standardized test methods
  - Designed and developed experimental tests facilities for thermomechanical evaluation
    - ➔ Actual and simulated industrial environments
  - Developed methods to predict service life under varies operating conditions
  - Collaborated with various industrial partners in developing CFCC fans for metal heat treating furnaces

# Advanced Materials Processing – CFCCs

- Further investigation of CFCC materials
  - SiC-based CFCCs possess outstanding properties, but lack stability in some industrial environments
  - Investigate alternative material systems in collaboration with industrial partners
  - Proposed to evaluate all-oxide CFCCs
    - ➔ Alumina or mullite matrices reinforced w/ mullite-alumina fibers
  - Evaluate and develop primary processing methods for reliable and cost-effective fabrication of CFCCs

# High Density Infrared Plasma Arc Lamp Processing

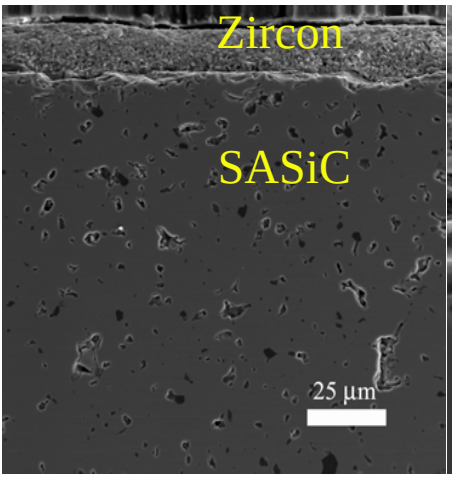
- Single source 300,000 Watts
- Radiant output is short wavelength, 0.2 – 1.4 microns
- 2% to 100% of available output, continuously variable
- Change power levels in less than 20 milliseconds
- Electric to radiant energy, 55% efficient
- Large process areas – 10 by 20 cm uniform irradiance
- Limited convective mixing
- Rapid cooling
- Minimal effects on the base material
- No temperature limitations, readily melt tungsten

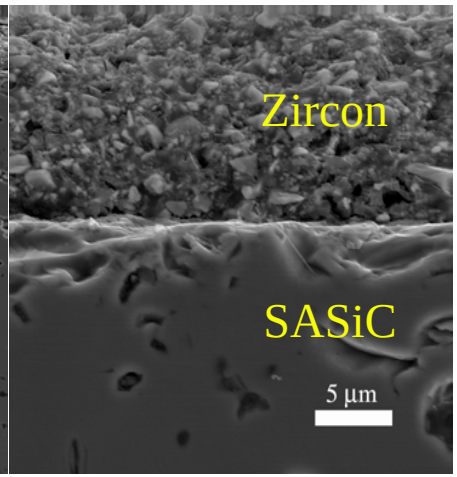


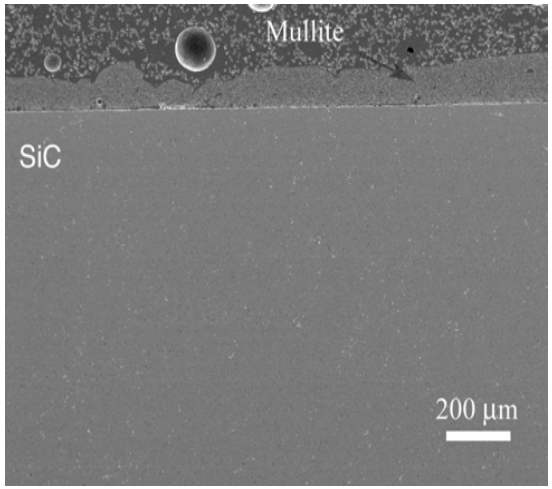
# Advanced Materials Processing – Coatings

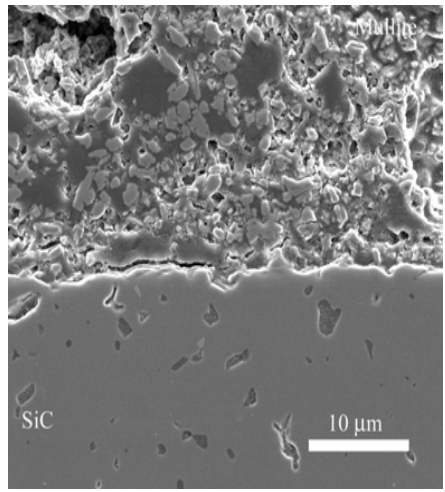
- Varity of slurry-based coating processes
  - Vacuum infiltration, spin coating, screen printing, pad rolling, spray coating, and dip coating
  - Each have their advantages and disadvantages depending on the complexity of the component
- Main purpose of these coatings is for environmental protection of the underlying metal or ceramic

# Environmental Barrier Coating (EBC)



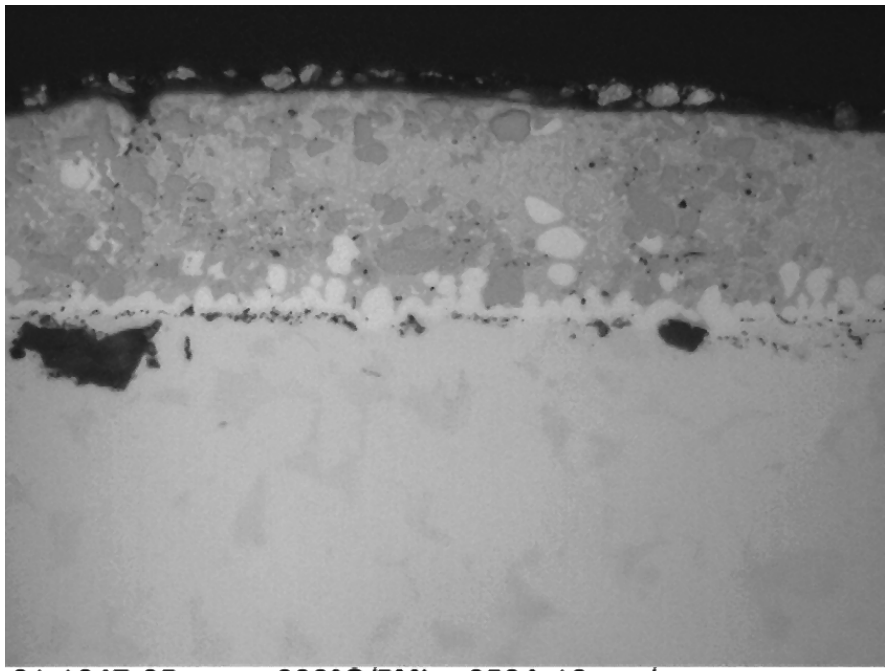




- Zircon ($ZrSiO_4$) coating on sintered-α SiC
- Screen printing and densified utilizing HDI processing

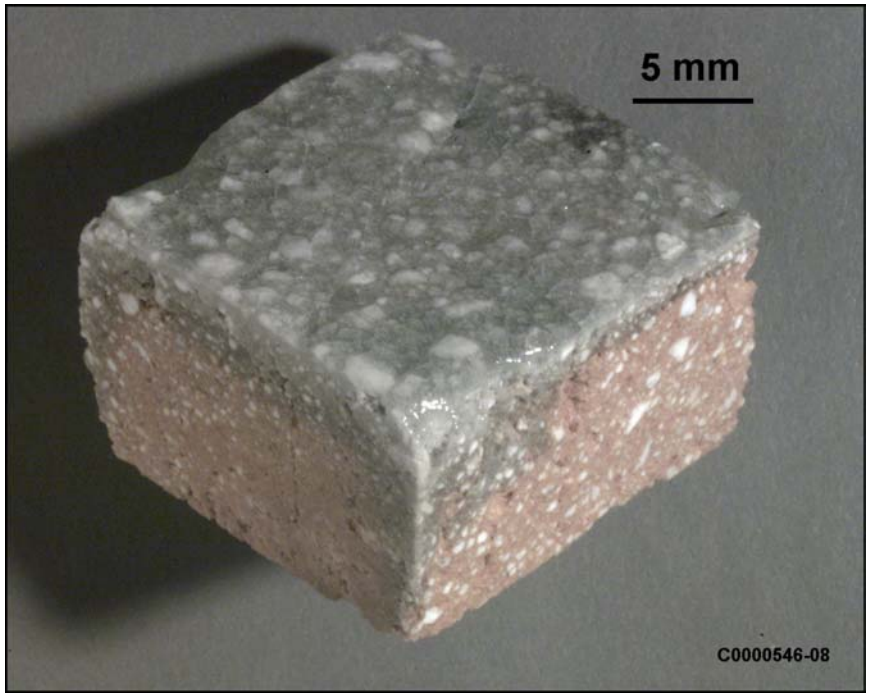
- Mullite spray coating on SiC
- Conventionally sintered at 1600°C for 2 hours in air

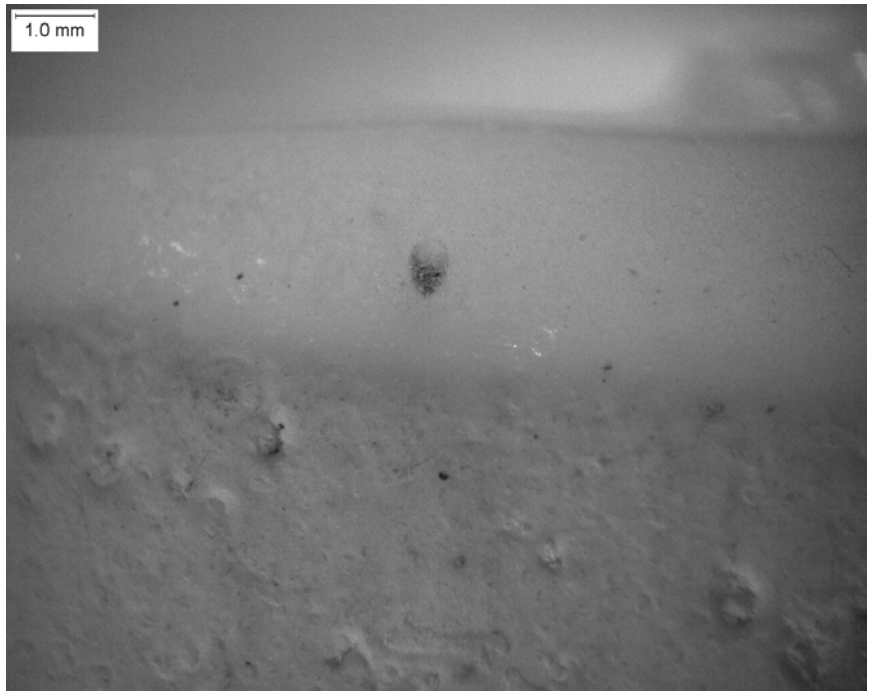
# Coatings Fused on Metals




- Tungsten carbide sprayed coating on steel
- Utilizing HDI processing

# Surface Modification of Ceramics




- Densified the surface of a mullite brick utilizing HDI process
- Power density of 800 W/cm$^2$

# Advanced Materials Processing – HDI Direct Intermetallic and Composite Sheet Fabrication

- Ordered intermetallic alloys based on TiAl, $Ti_3Al$ and composites are attractive for high temperature applications
  - They possess low density, high melting temperatures, good high temperature properties and oxidation resistance
  - Low cost processing is achieved by direct fabrication of sheet from powder with high-power density radiant energy
  - Typical processing rates are 1 - 5 cm/second
  - Sheet widths of up to 35 cm presently
  - Sheet thicknesses of greater than 0.04 inch to less than 0.001 inch
  - Estimated production cost of nearly two orders of magnitude less than ingot metallurgy, TiAl

# Proposed Activity

- Develop advanced materials utilizing the discussed techniques with enhanced environmental resistance:
  - Improved corrosion and creep resistance
    - ➔ Longer life and reduced furnace down time
  - Lighter weight construction
    - ➔ Resulting in easier installation, less maintenance and reduced energy consumption
  - Higher temperature capability
    - ➔ Resulting in greater durability and allowing removal of ancillary cooling equipment
    - ➔ Increased processing temperature to be attained, improving process efficiency
- Advance the processing methods to develop reliable cost-effective advanced materials

# Proposed Activity

- Composites
  - Slurry processing utilizing HDI sintering
    - Infiltration of fiber mat
    - HDI processing to densify composite
    - HDI process is a reactive approach that is rapid and has the potential for a continuous process, decreased costs
  - CFCC processing methods
    - Focus on all-oxide CFCCs
    - Alumina or mullite matrices reinforced with mullite-alumina fibers
      - Offer attractive high temperature properties and stability in a variety of environments
    - Develop primary processing methods for reliable cost effective fabrication of CFCC in calibration with industrial partners